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# Technological Progress in a Common-Pool Resource: Revisiting the Lofoten Fishery

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# Preface

As the last few days of writing comes to an end, one starts to reflect on the process of writing a master's thesis. Naturally, things are seen in a different light; put into a larger perspective. While mostly being fun, at times it has felt like a thousand-piece jigsaw puzzle scattered on the floor with the solution hidden far away.

Putting those pieces together would not have been possible without the help of many people; more than I can mention here. Still, I want to acknowledge the following contributions. First of all, to my supervisor Florian K. Diekert. This thesis would not have gone anywhere without his ideas, careful help and comments; at every important stage of the process. I am grateful that you had the opportunity to supervise on the thesis.

For helpful comments, suggestions and discussions I thank: Frikk Hugo Bø Nesje, Maria Razmyslovich, Nicolai Ellingsen, and to the participants of the Marine group seminar at NorMER. Thanks to Eivind Hammersmark Olsen for help with typesetting in TEX. Thanks to Mikkel Myhre Walbækken for comments and helpful suggestions to the text. None of the people mentioned should in any way be held responsible for mistakes or errors. Thanks to the Centre for Ecological and Evolutionary Synthesis (CEES) for providing me with a nice working environment, office space and a computer, as well as a scholarship from the REPIN project.

Lastly, I want to thank my friends and my family. This could not have been achieved without the help from them all along the way.

*Eivind Oland Stjern*
Oslo, May 2014

# Abstract

This thesis scrutinize the insight from emerging theories on cooperation in common-pool resources. The models of co-management were inspired by examples of *collective action* among people, which is in stark contrast to the prominent "tragedy of commons" metaphor. The focus in this thesis is on the effect of technological change on the co-management of a natural renewable resource. The fishery of Lofoten is explored during the years 1864–1988, as this fishery has been regarded as an example of successful co-management. It had for instance a local governance structure that integrated the fishermen into the decision making process. Furthermore, the fishery of Lofoten is well-documented with the annual Lofoten reports (*"Lofotberetningene"*). The data set is extracted from these unique historical documents.

During the years of 1905–1920, a rapid technological progress occurred as the share of motorized vessels increased from 0 to 40 per cent. This period coincide with increasing violations of the co-management rules and regulations. A regression model is used to measure these violations, which serves as a proxy for defection in the co-management. The result shows that a shock in motorization was associated with a strong and significant effect on violations of the rules and regulations. Furthermore, it suggests that technological change affects the cooperation of a common-pool resource. The strain on cooperation would then increase because of the chances of higher effort and gear conflicts in the fishery, due to higher mobility and speed.

The findings encompass the emerging theories, and it shows that a rapid technological change is associated with a significant eroding cooperation in a common-pool resource. It shows that the pressure towards stronger monitoring and enforcement is associated with increasing technological progress.

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# 1 Introduction

Does cooperation in a common-pool resource erode during technological progress? This question needs to be answered as theories of co-management in resources have emerged in the latter part of the 20th century. The aim of this thesis is to enlighten this issue. The theories of cooperation in co-managed resources emerged contrary to the conventional held view in Garrett Hardin's "The Tragedy of the Commons" (Hardin, 1968). A metaphor which has been frequently used to describe the free entry problems of common-pool resources (CPR). Overwhelming examples contrary to the view expressed of the problem of individual rationality have been advocated by many; notably Elinor Ostrom, Oliver Williamson and Douglas North; examples of people taking *collective action* solving the commons. This is in stark contradiction to the held belief that individual rationality leads to collective irrationality.

Natural resources and environmental quality are typically characterized by free-entry. That is because environmental qualities such as clean air, water, and resources as forests and the fisheries, usually are difficult to exclude users from. It may be unfeasible to exclude users from the common due to reasons of high costs of monitoring or transboundary issues. Hardin's metaphor has been modeled as an $n$-person prisoner's dilemma, known as the CPR game. This illustrates the problem of a renewable resource such as the fishery. In this stylized version, it is assumed that the users are unlimited and that each and every one are acting according to what is individually rational. There are no rules or regulations governing the resource and the CPR is characterized by *free entry*.

Two externalities arise in this situation. Firstly, there is an externality arising from the fisherman struggling to harvest before the others, which leads to gear conflicts and to suboptimality as too much effort are put into the harvesting. This is characterized as the contemporaneous externality (Stavins, 2011). Secondly, as the fishermen harvest as much as they can manage, an externality arise as the stock is driven down by the excessive effort of the harvesting. This is the stock externality; or the *intertemporal* externality, to emphasize the dynamic aspect of the issue (Dasgupta, 1982, p.17).

These type of CPR problems grow stronger every day, as many resources are depleted at a far too rapid pace. Resources that may soon reach critical values of carrying capacities, cause growing concerns (Stavins, 2011). Especially because renewable resources and environmental qualities may show resilience, but once critical regenerating capacities are reached, systems may suddenly switch to worse steady-states (Scheffer et al., 2001). It may be too costly or unfeasible to reverse to old steady-states once the changes has occurred (Arrow et al., 1995).

The suggested solution to the commons has typically been either privatization or state-control; as in a question of whether full property rights or individual transferable quotas were to be utilized. However, cooperation among the users could just as well be a means of solving the commons. Elinor Ostrom argued that people may just as well cooperate, they do not always act selfishly or ruthlessly as examples on the contrary exists. Furthermore, she argued that strong regulations may not always be beneficial. They may frustrate and constrain, rather than facilitate private initiative among people (Ostrom, 2000). Ostrom looked at various ways and methods to incorporate local governance. Her point was not to glorify collective action, it was rather to find solutions to the commons when neither privatization nor strong regulations were feasible.

There are numerous papers and studies in the field of collective action and cooperatives in the commons, and the discussion goes all the way back to Katharine Coman's (1911) study of "Unsettled Problems of Irrigation" in the American West (Coman, 1911; Stavins, 2011). She recognized and discussed the type of problem faced by externalities from irrigation, and pointed out that members of a religious group where able to solve the problems by "coöperative effort" [*sic*] (Coman, 1911). Later, the problem of commons was put into a new context with the fishery, and elaborated and analytics discussed and analyzed by Scott Gordon (Gordon, 1954). The issue has also been studied by Martin Weitzman, in a discussion on open-access versus private property (Weitzman, 1974). The insight from these two papers is that the users average products is equated in a CPR, as in contrast to the marginal product. Developments in capital theory and dynamic modeling led Colin W. Clark to utilize stock dynamics of a renewable resource and incorporate into a benevolent planner's problem (Clark, 1990). By incorporating individual transferable quotas (ITQs), and the equimarginal principle, the solution would ensure optimality under given conditions, such as well-defined, enforceable property rights.

Inspired by the case studies and lab experiments[1] of cooperations, Sethi and Somanathan (1996) integrated game theoretic modeling and resource stock dynamics into their common-pool resource model. The model of a common-pool resource game with cooperation among the users was based on social norms of reciprocity. Stable steady-states of cooperation depended on the share of the users cooperating, a share who had preferences for enforcing the law, and the ones who where defecting from the cooperation. There where three important parameters for the cooperation; technology, population and price. The mechanism of new technology makes the upside from 'cheating' on the cooperation higher, due to increasing possibilities of catching before the others and because new technology would lead to more harvesting which would drive down the resource stock in a later period. An increasing population makes the crowding externality more severe, and increasing prices puts a larger strain on the cooperation among the users. It leads to excessive effort, as in for instance gear conflicts, and higher chances of driving down the resource stock. The social sanctions and norms may erode altogether, if one or more of these parameters grows sufficiently.

Modeling impacts of opening up to international markets, Copeland and Taylor (2009) showed how regulations of a resource were endogenously determined. They identified three types of economies that emerged and named them Clark, Hardin and Ostrom after their contributions in their respective fields. The model predicts that increasing technology would lead to a need of stronger regulations of harvesting, because the excessive harvesting would drive down the resource stock as well as the rents in the fishery. Richter et al. (2013) modeled cooperation as a "norm-spreading," contagious process. They showed that cooperation may be resilient, but once exceeding a critical threshold value, the cooperation may collapse. Cooperation critically depended on the share of

[1] Notably the paper "Evolution of Cooperation," revealing that cooperation could emerge and sustain in an a-social world (Axelrod and Hamilton, 1981)

cooperators in the community. These changes in "the strength of the social dilemma" depended critically on technology, population and prices. Because of multiple equilibria, reversing such a process might be costly.

To the best of knowledge, there is little in the field of empirical studies of cooperations based on real-world data. Such research is hard to come by, in contrast to the frequent papers of lab experiments and case studies. Although the empirical studies of cooperation in CPRs are few and far between, a paper that to some extent is related to this field, is the study of technological changes in Lofoten by Hannesson et al. (2010). Puzzled by the low productivity in the Lofoten fishery, they looked at technological changes in the open–access fishery of Lofoten during 1900–1988. In addition to the data from the Lofoten reports, the study utilized estimates from stock assessment models and productivity indices from agriculture and industry. Their main finding was that technological gains were almost neutralized by the "tragedy of commons." They argue that excessive effort and participation in the fishery most likely led to rent dissipation and a decline in the fish stock.

The lack of previous studies in this empirical field has posed certain challenges in the project, as there were little correspondence to be found. At the same time, these events to be studied goes back over a hundred years ago, and thus the picture of the events are first revealed in light of the historical research. This thesis is a study of the cooperation in a CPR, by looking at the impact of a local governance structure during a shock in technology. The co-management has a legal framework allowing supervision by the authorities, where the rules are set by the committees of fishermen. Furthermore, the success of this co-management will depend critically on the number of people who follow the rules, and those that break them. Does the violations of the rules and regulations in a co-managed resource increase in a period with strong technological developments? This thesis hypothesis is to be tested: Violations of the rules and regulations set by the co-management will increase during a rapid technological change.

## 1.1 Background

The hypothesis will be tested on the fishery of Lofoten. The fishery was an open-access resource over 130 years. During this period, there was no regulations regarding participation or catches, just regulations regarding the fishing grounds on gear-types and time-allowance.[2] The fishery in Lofoten has for various reasons been held as an example of a successful co-managed resource (Janssen and Ostrom, 2006, p.60). The fishery had a local governance structure, with committees that met and set the rules and regulations. These rules and regulations were governed by a local structure and authorities present with enforcement (Jentoft and Kristoffersen, 1989). The local governance structure was in many ways in line with the principles that Elinor Ostrom claimed to be vital for co-management: Principles such as "Clearly defined boundaries," "Collective choice arrangements" and "Monitoring" (Ostrom, 1990, p.90). But one should point out that – however successful co-management – the system ended in the early 1990s. It is outside the scope of this thesis to discuss the matter further; since the focus is on technological progress during the years1905–1920, one can only point to the discussion in Holm et al. (2000).

Furthermore, the data are from unique historical documents, namely the annual Lofoten reports (*"Lofotberetningene"*). There was a shock in the technology during the years of 1905–1920 as the the fishing fleet in Lofoten saw a rapid increase of the motorized vessels. This technological progress is combined with records in the reports on violations of the co-management rules of Lofoten. The rules and regulations regarding time allowances and fishing grounds will proxy for defection in the co-management. This work discusses if technological change erodes cooperation in a CPR, and more specifically, it tests if the motorization of the fishing fleet in Lofoten led to increasing violations of the co-management system.

A regression model is presented which proxies for defection in the co-management. The results show that the motorization was associated with a strong and significant effect

[2] Note that the fishery of Lofoten was not open-access with respect to gear types (Jentoft and Kristoffersen, 1989).

on violations of the rules and regulations during the years 1905–1929.[3] Furthermore, the result suggests that technological change affects the cooperation of a common-pool resource. The strain on the cooperation would then increase because of the chances of crowding and effort in the fishery increased due to higher mobility and speed. In addition, the process is likely to have been catalyzed by other technologies such as the telegraph.

The findings encompass the emerging theories, and shows that a significant technological change is associated with eroding cooperation in a common pool resource. It shows that the pressure towards stronger monitoring and enforcement is associated with increasing technological progress.

[3]All the figures and regressions have been carried out using the statistical software package Stata 13, as well as some calculations in Microsoft Excel.

# 2 | Materials and Method

This chapter is organized as follows. Section 2.1 presents a brief historical context of the Lofoten reports in order to gain an understanding of the origins of the data set and the setting. Section 2.2 presents the major developments in the legislation of the Lofoten fishery, which eventually led to the co-management system. Section 2.3 presents the descriptive statistics for the variables which will be utilized later in the estimation. The emphasis in this section will be to elaborate on possible reasons for the various changes over time. Lastly, section 2.4 presents the regression model, and the section will elaborate on the estimation method.

## 2.1 Data

The history of the Lofoten fishery span over hundreds of years. It goes back to at least 800 A.D., as events taking place at that time are referred to in "Egil's Saga" (Hannesson et al., 2010). Later, around 1100, dried fish became an important item of trade in Europe with an increasing population living in the cities demanding food which they could not supply themselves. The stock fish from Lofoten was the main reason for the Hanseatic trading post in Bergen. This led to the city of Bergen's rapid expansion from the foundation in 1070, becoming the largest city in the country up until the 1830s (Hannesson et al., 2010; Christensen, 2009, pp.8–9). Lofoten is the spawning area for the Northeast Arctic Cod, which takes place every year in the months between the late January to late April, as the islands of Lofoten provides ideal conditions for spawning.

From 1859 – the "Free Law" of Lofoten was effective – and reports on participation and landings were registered. These reports were published under *"Om Lofotfiskeriet"* in 1859–1878, and as *"Aarsberetning vedkommende Norges fiskerier;"* under *"Lofotfiskeriet"* in 1879–1922 and *"Lofotfisket"* in 1923–today. In the beginning, the annual Lofoten reports were brief, with texts describing the participation, catches, weather and violations of the laws of Lofoten. However, around 1860–1880 the reports increased rapidly in details, as tables with data and summary statistics were introduced and discussions of various kinds related to the fishery were reported. The reports contained data on for instance temperature, diseases, lodging, telegraphs sent and received. They reached a maximum of 211 pages in 1881. Later reports, however, were more compact due to developments in typesetting. Typically, these reports contained a hundred pages long of data from the fishery. These reports continue as of today, but consists only of a few pages. Reports are issued by the Directorate of Fisheries in Bergen, and are available as electronic documents from the library at the Marine Research Institute in Bergen.[1]

By studying these reports, the relevant data for the thesis have been transferred, typing in the values from the reports in portable document format (PDF) into Excel-files. Controlling for errors – such as mistyping – the cells in Excel has been added, and then compared to the summary statistics in the reports. This process has been time-consuming, but accurate. Lastly, the data has been grouped into relevant categories for estimation, and transferred into Stata-files. Issues on consistency arose as some variables were redefined during the time frame set. For these variables the matter will be dealt with in the descriptive statistics subsections.

## 2.2 Co-Management Evolving

The history of the rules and regulations which eventually led to the co-management in Lofoten goes back to 1816. A new law was imposed to resolve conflicts over gear types in order to generate income after the Napoleonic Wars (Solhaug, 1983, pp.79–84). The "Law of Order" divided the fishery into sectors, each tied to the control of a merchant (*"væreier"*). The law made the merchants powerful, as the fishermen had to hire a place in their lodges and pay rents on the fishing grounds. This led to conflicts over ownership and rights, as the law was not intended to solve the distributional aspects that came about (Solhaug, 1983, p.134).

[1] http://biblioteket.imr.no/e-tidsskrifter/omlofotfiskeriet/

The “Free Law” of 1857 was introduced to solve that. The law echoed the prevailing belief in *laissez-faire* economics (Solhaug, 1983, p.134); the liberalistic idea of letting a free market resolve conflicts with only a minimal governing body. A law that must be seen in light of the major contributions of the minister Ketil Motzfeldt and his principles of *“Fritt hav, fritt fiske og offentlig oppsyn.”*[2] (Coldevin, 1946, p.64) The idea was to put aside formal regulations – but to keep a strong enforcement – by letting the fishermen decide which sectors the specific gear types could be used in. The law made the fishermen free to move wherever the fish might spawn instead of being locked to the merchants sectors and lodges, *de facto* making Lofoten an open-access fishery (Jentoft and Kristoffersen, 1989).

Although fishermen could move freely on the fishing grounds, the law gave bigger boats an advantage. The steamships were experimenting with seines, and tended to dominate over the smaller boats. To illustrate the point: In 1888 and 1890 it was an abundance in the narrow fishing grounds of Østnessfjorden and Trollfjorden. In 1888, the steamships did not manage to completely close off the fjord, but anger grew among the fishermen. This led to the “battle” of Trollfjord in 1890, as this time the steamships managed to close off the narrow fjord completely. The fjord was covered with ice, and the large steamboats cleared the fjord by breaking it off. The steamships tied together and demanded fees from the fishermen for access to the fjord (Solhaug, 1983, p.156).[3]

In the wake of these conflicts – as of 1893 – seines and trawls were banned altogether (*“Posenot, Synkenot, Slæbenot og Trawls.”*) (Solhaug, 1983, p.157). And later – in 1897 – the “Lofoten Law” was enacted. This law remained in principle the same for the rest of the period in which Lofoten was an open-access resource. A system that gave the fishermen more power, as local committees of fishermen decided more specific rules and regulations to co-manage the fishery (Jentoft and Kristoffersen, 1989). The system was changed in the 1990s, as the 1980s saw a decline in cod abundance followed by problems of getting the governing committees to meet (Holm et al., 2000).

[2]“Free fishing grounds, unregulated harvesting and public enforcement of law.” (Author’s translation)

[3]Johan Bojer later dramatized the event in the novel “Den siste viking” (*The Last of the Vikings*) (Bojer, 1921).

Table 2.1: Summary Statistics

| **Variable** | **Mean** | **Std. Dev.** | **Min.** | **Max.** | **N** |
|---|---|---|---|---|---|
| Fishermen | 17959.088 | 8569.460 | 2347 | 32600 | 125 |
| Boats | 4815.584 | 2122.13 | 905 | 9599 | 125 |
| Catches | 21460.696 | 8853.556 | 6120 | 48727 | 125 |
| Motor | 2292.69 | 1199.397 | 3 | 4726 | 84 |
| All violations | 273.48 | 235.48 | 2 | 996 | 125 |
| Paragraph 16 | 183.104 | 195.947 | 1 | 972 | 125 |
| Paragraph 22 | 30.808 | 89.049 | 0 | 577 | 125 |

Source: The Lofoten reports (1864–1988)

## 2.3 Descriptive Statistics

Table 2.1 shows summary statistics for variables to be presented in following subsections. The period set is 1864–1988. This time span is set for two reasons. Firstly, a report from 1863 is unavailable and data on violations cannot be found elsewhere in the following reports. This makes 1864 the first year from which the series follows undisrupted. Secondly, although the period of open-access in Lofoten formally ended in the early 1990s, already in the late 1980s some regulations occurred. For instance, the fishery was closed in the middle of the season. Following Hannesson et al. (2010), the series ends in 1988 so these events would not affect the data. This makes the entire sample 125 years of historical undisrupted data from an open-access resource.

### 2.3.1 Participation

Reports on participation are census data. A date was set when the participation was most likely at its peak. The 16th of March was chosen, as typically most fishermen had arrived while few had departed (Solhaug, 1983, p.13).[4] From 1860, reports on participation were divided into fishermen and boats on three gear types; gill nets, long lines and hand lines. After 1950, seines were included.

Some issues in regard to the accuracy need to be mentioned. There could possibly be errors due to for instance fishermen leaving earlier than the 16th of March, participation taking place in areas not covered by the authorities and fishermen mistakenly registered

[4] From 1918 the 22th of March.

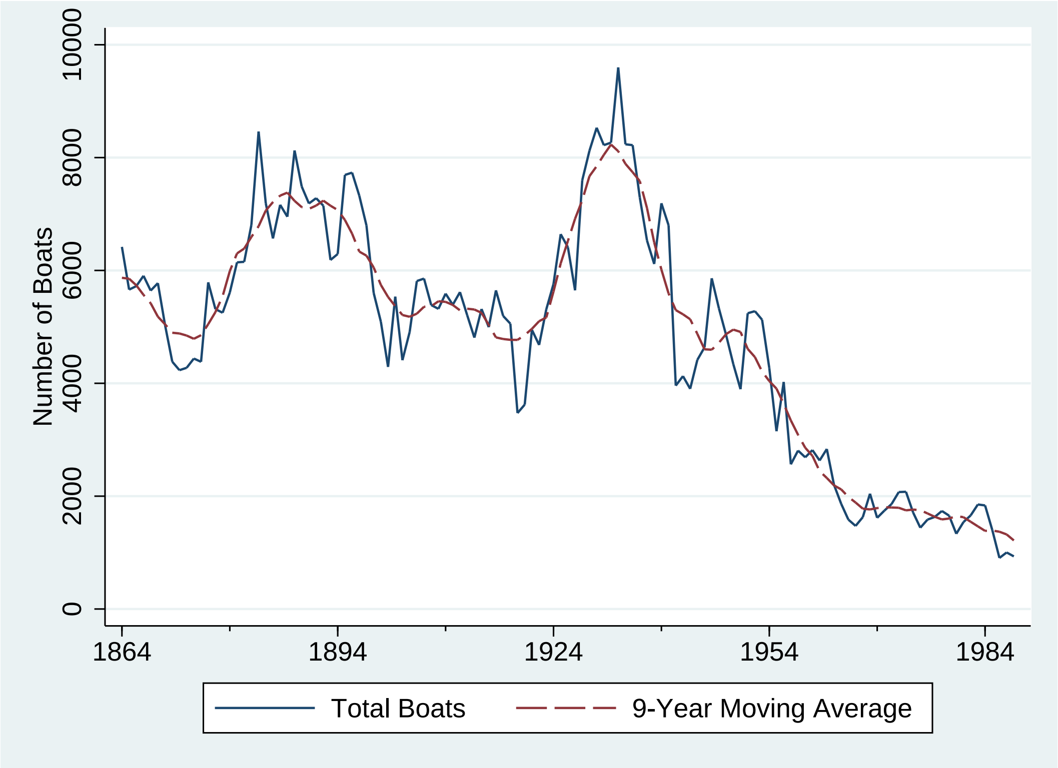


Figure 2.1: Boats in Lofoten (1864–1988)

twice. However, the issues mentioned are negligible. Reporting were synchronized and the largest participation taking place within reporting districts, leading to relatively reliable data (Vea, 2004, p.93). Weaknesses or irregularities in data were even pointed out by the overseer, with suggestions and comments in the reports (Solhaug, 1983, p.13).

Figure 2.1 shows participation of boats during 1864–1988. A series with raw data and a moving average filter centered on 9 years are shown. Fishing boats in Lofoten reached a maximum of 9599 in 1933, and a minimum of 905 in 1986. Three periods need to be commented on: First the period 1876–1895, which can be seen in light of the declining abundance of herring in Nordland and Troms, as many of the fishermen were returning to Lofoten (Solhaug, 1983, pp.176–178).[5] Second, the increasing participation during the

[5]The herring fishery in the 1870s was held to be a hazardous gamble to bet on, as the abundance were volatile compared to the relatively reliable cod in the Lofoten. Large fluctuations in income led some fishermen to excessive consumption during the good times, and little savings when the bad times hit, as caricatured in Knut Hamsun's novel *"Landstrykere"* (*Vagabonds*) (Hamsun, 1927; Solhaug, 1983, p.674).

period 1930–1940, coinciding with the great depression in the 1930s. The increased participation can be seen in light of few other outside opportunities (Vea, 2004, pp.113–114). Some of these years had many unskilled fishermen participating, as a discussion in the 1935 report touches upon, reasoning that this was because of the high unemployment (ANF, 1935, pp.19–20). Third, the period 1950–1988, contrasting the previous period as participation declines, which can be seen together with the economic growth in Norway (Hannesson et al., 2010).

A figure on participating fishermen has been omitted, as the pattern is almost identical to that of boats. The correlation between fishermen and boats is indeed 0.9647. Clearly, the insight from the figure of boats may also transfer to that of the fishermen. Participation of fishermen reached a maximum of 32600 in 1895 and a minimum of 2347 in 1986, and was well above 30000 fishermen both in the 1890s and in the 1930s.

### 2.3.2 Catches

Data on catches were registered from the beginning of the reports in 1859. During 1859–1928, registration of catches were in thousand individuals, and as of 1929–, in biomass. In order to consider the whole period 1859–1988, the catches in 1929–1988 has been converted into thousand individuals.[6] To convert biomass into individuals, stock assessment models on age compositions and weight has been used. Data on the fish stock in 1929–1944 is based on Hylen (2002) and in 1945–1988 on Opdal (2010). Although the data on the stock composition is far from perfect, at present this is the best historical data available from Lofoten. The precision of the stock data used for transformation in the years 1929–1988 is likely to improve over this period.

Catches in Lofoten for the period 1864–1988 are shown in figure 2.2. The maximum in this period was 487272 (thousand individuals) catches in 1947, and a minimum of 6120 (thousand individuals) catches in 1918. There are three factors which could shed some light on the fluctuation of the catches. i) Abundance of the stock, ii) the location of the spawning cod on the fishing grounds and iii) the effort exerted from harvesting. The declining abundance of the stock during 1879–1920 was due to a long-term shift in distri-

[6] I am in debt to Florian for these calculations.

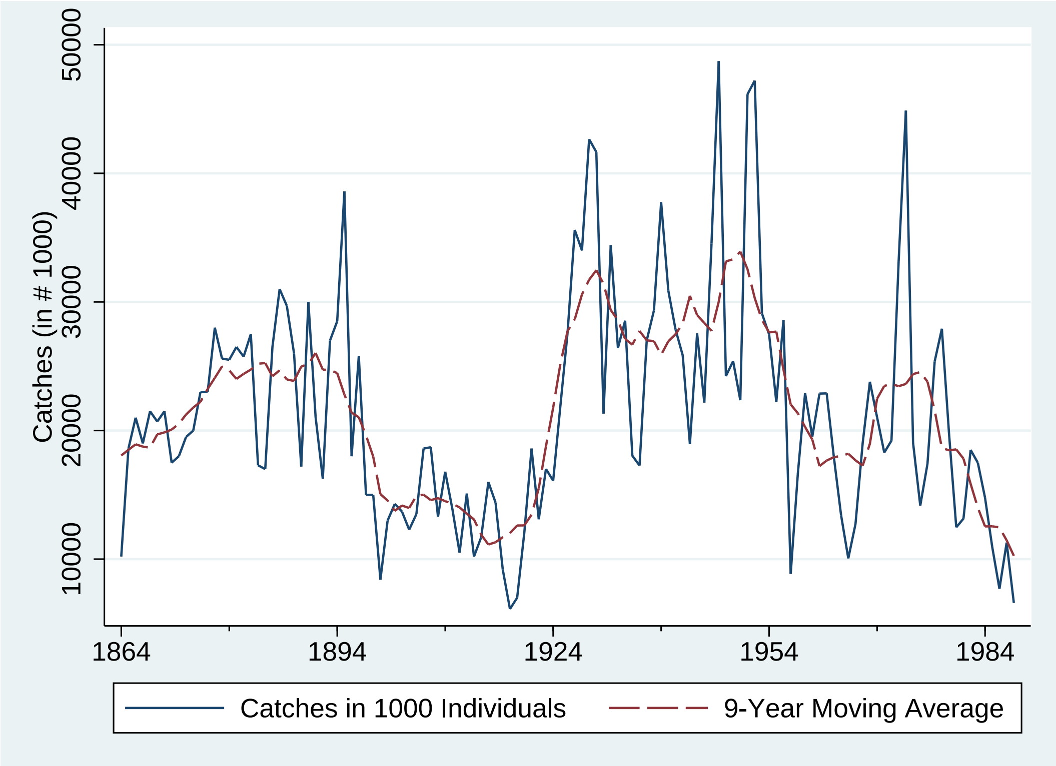


Figure 2.2: Catches in Lofoten (1864–1988)

bution and migration of the cod. Increasing temperature in the waters during 1920–1930 was a likely reason for the higher catches 1930–1940 (Nakken, 2008). During 1940–1945, trawling outside of Lofoten was offset by the war, which can to some extent explain the large catches in 1945–1950, as the absence of factory trawlers in the North Atlantic made the stock regenerate (Godø, 2003). The declining trend in catches during 1955–1980 can be seen in light of harvesting outside Lofoten. During this period, there was a declining trend in the stock to a large extent caused by harvesting in the North Atlantic Sea, as catches were frequently above the recommended levels (Nakken, 2008).

### 2.3.3 Catches to Boats

Figure 2.3 showing catches to boats. Graph shows little growth, mostly below 5 (thousand individuals per boat). From about, 1939 the ratio starts to increase. Boats can be interpreted as a measure of effort in the fishery, even though it may not fully reflect intensity of effort (Hannesson et al., 2010). Two points in may be noticed. The first is

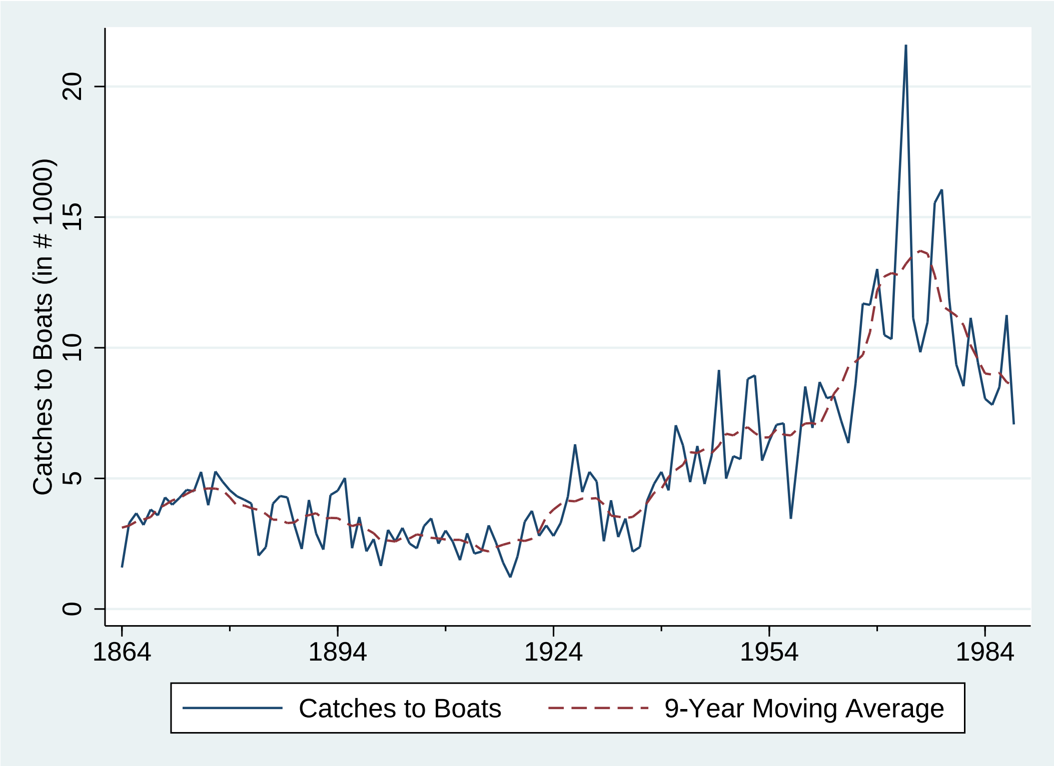


Figure 2.3: Catches to Boats (1864–1988)

related to rent dissipation. More boats participating leads to a lower catches to boats ratio. The rent of the fishery declines in the number of users (Gordon, 1954; Weitzman, 1974). This is probably the reason for the low ratio during most of this period up to the 1950s. Secondly, the ratio also reflects technology. Increasing average product in the 1950s most probably were due to better technology, and thus higher efficiency. However, that may only be the in short run, as overexploitation will dive the stock down for later periods. This could be a possible explanation for an increasing ratio from the 1950s followed by the decline in the late 1970s.

### 2.3.4 Violations

From the first report in 1859, and throughout the whole period of interest, the violations of the Lofoten laws were registered. Although there are changes in the legislation and regulations throughout the whole period, the time-series from the reports are relatively consistent, in a sense that they report on variables that can be interpreted as the same

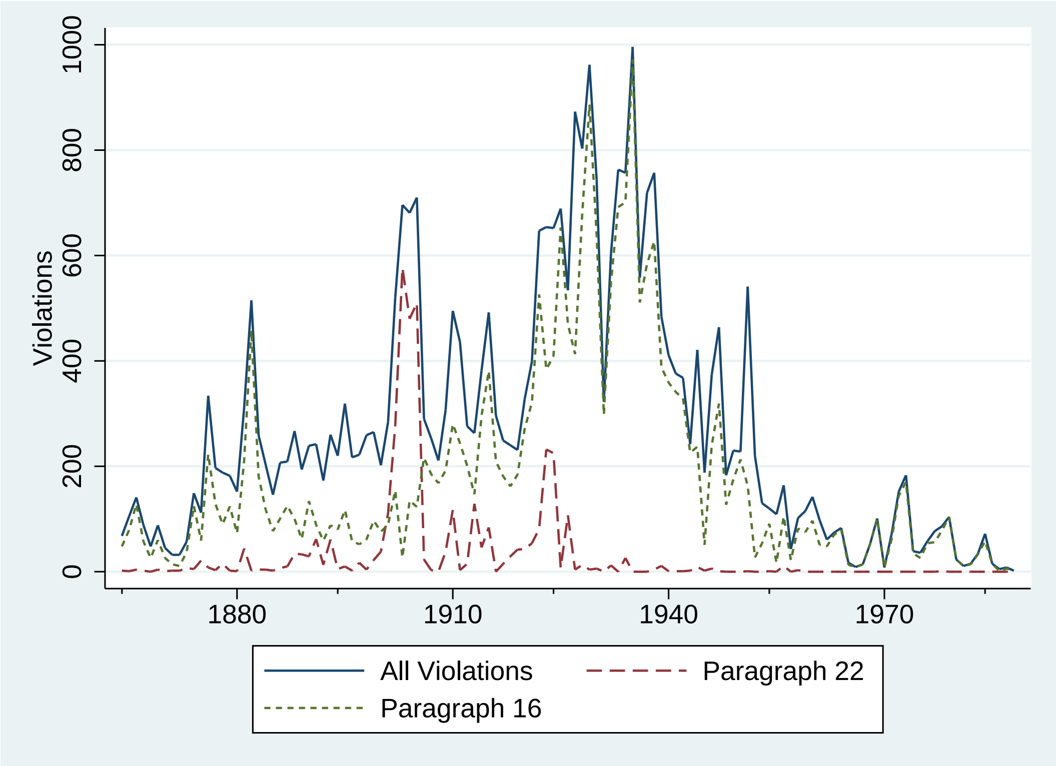


Figure 2.4: Violations of the Lofoten Laws (1864–1988)

over the entire period. But one has to be careful, keeping in mind the historical background when looking at the data. The first years of reporting violations are probably not accurate, as the actual violations may have been higher. Unreported violations of the "Free Law" were numerous, which is in stark contrast to the few reported violations during those first years (Jentoft and Kristoffersen, 1989). The low number of actual reported violations is probably due to the high costs of keeping a control force. But reporting and enforcement improved, as the main conflict during those years was resolved when the "Lofoten Law" was enacted in 1897. The system from 1897 was evaluated and revised in 1950, and this evaluation turned out in favor of the "Lofoten Law." The committee applauded the changes of 1897 and the success of the system that integrated the fishermen into the local governance structure (Jentoft and Kristoffersen, 1989).

Figure 2.4 shows three series of violations in Lofoten during the period 1864–1988. In the first series, all violations of the rules and regulations are presented. The second series is of violations of §22, which is a regulation of fishing on public holidays and Sundays

(*"Overstaaen eller sætning paa helligdag"*). And the third series is of violations of §16. This is a composite index made that consists of §$16_\mathrm{a}$, which regulates the setting of gear types (*"Ulovlig sætning paa delt hav"*), and §$16_\mathrm{c}$, which deals with time regulations (*"for tidlig udror eller for tidlig sætning"*).[7] The period 1864–1935 were volatile when it comes to the total number of violations, but a trend in the sum of the violations is most apparent. The maximum of all violations for the whole period of 1864–1988 was in 1935, when a total of 996 violations were reached. This trend is reversed after the late 1930s, as the violations declines steady. The series reaches a minimum of 2 violations altogether in 1988.

As for the §22 series, throughout the period most of the violations of §22 are low. But during the period 1901–1906, there was an increase in violations. This was due to a conflict between long lines and gill nets fishers. It was resolved in 1905 with a new regulation. The report of 1905 argues that it was a little too late to effectively reduce the violations in that year (ANF, 1901–1906), whereas the following year, violations of §22 drops from 510 to 23. This must be seen in light of the changes in regulations.

In regard to the series with violations of §16, there is a spike during 1881–1882. This was a conflict driven by changing location of fishing grounds, as spawning started to relocate in sectors that were reserved for long lines. This was most unfortunate for the gill nets fishers, and led many of them to violate the law by fishing with gill nets in the sectors reserved for long lines. One should keep in mind that having both gill nets and long lines was too costly for many of the fishermen (Welle-Strand, 1942, p.50). The 1882 report explains that some fishermen were weighting the benefits from getting larger catches versus the cost of penalty, as the authorities had some problems of monitoring the situation (*"Imidlertid kunde det ikke undgaaes, at Enkelte "satte paa Mulkten," d.v.s. satte ulovlig paa Linehavet og betalte sin Mulkt i Forventning om i en rig Fangst at finde Dækning her-*

[7]The reporting of the series change over time with the legislation. However, there is strong correspondence, indeed, even the reports effectively treat them as equal. §22 corresponds in 1859–1897 to §19 (*"Overstaaend paa Helligdag"*) and to §6 in 1956–1988 (*"Setting av redskaper på helligdag, lov om saltvannsfiskeriene"*). §$16_\mathrm{a}$ corresponds in 1859–1897 to §11 (*"ulovlig Sætning paa delt Hav"*) and to §55 pkt.1 (*"Ulovlig setting av garn på linehav, lov om saltvannsfiskeriene"*) in 1956–1988. And lastly, §$16_\mathrm{c}$ corresponds in 1859–1897 to §10 (*"fortidlig Udroning eller fortildig Sætning"*) and in 1956–1988 to §55 pkt.2 (*"Fortidlig utror, lov om saltvannsfiskeriene"*).

*til. . . ”*)[8] (ANF, 1882, p.6) The following year, the number of gill nets drops from 11258 to 7804 and long lines increases from 14392 to 19753 (ANF, 1882–1883). Therefore, the conflict ends as the violations drop in 1883. This conflict serves to illustrate many of the conflict over gear types typical of Lofoten during the period 1860–1890, though they may not have been of the same magnitude. These conflicts were mostly driven by the changes in spawning grounds (Solhaug, 1983, pp.173–180).

During 1900–1940 violations of §16 increased rapidly, but with 1931 as a notable exception. The Lofoten report argues that the particularly low abundance of cod in combination with the depression must have had a disciplinary effect on the fishermen (*“Som det vil sees er bøteantallet gått sterkt ned . . . Grunnen hertil må søkes i det minimale fiske . . . samt at fiskerne p.g.a. de dårlige tider mest mulig søker å undgå bøtestraff ”*)[9] (ANF, 1931, p.6). This year must be regarded as an exception, due to a lower opportunity cost of cooperating, as compared to the years 1920–1940 with higher catches. Indeed, the reports in the years 1930-1933 show that quantity fished was particularly low in 1931 with 65100 tonnes. This compared to 127200 tonnes in 1930, 105101 tonnes in 1932 and 80695 tonnes in 1933.

The violations of §16 drops around the year 1940. There are three possible reasons for this which will be comment on. Two of the reasons are due to monitoring and regulations, and the third one is due to exogenous variation, such as changes in the weather and abundance of the spawning grounds.

First of all, the violations would drop if the enforcement became stronger. For instance, more control vessels would be disciplinary on the fishermen, as the chance of being caught violating the rules would increase. Indeed, the report of 1931 even comments on experiments with using an extra vessel in the control force, as they were trying to handle the present conflicts. From the report of 1931, *“Som anført i fjorårets beretning, viser det sig fremdeles at 3 skøiter er for lite . . . Kommende vinter vil der bli innsatt 4 opsynnskøiter*

[8]“It could not be avoided, that some were “betting on the fine,” i.e. were gillnetting in the lines’ sector and paid their fine in expectation of richer catches to be had.” (Author’s translation)

[9]“As evident in the report, penalties have greatly declined . . . The reason must be the low catches . . . and that the fishermen due to hard times try to avoid penalties” (Author’s translation)

*i opsynstjnenesten i den travleste tid."*[10] (ANF, 1931, p.8). It indicates that such experiments might have been the reason for the later decline, and the report of 1936 comments on the need of extra vessels in the districts: *"sjøopsynet* [ble] *iår ytterligere forsterket med en skøite, og man kunde derfor overkomme å stasjonere opsynsskøiter i alle distrikter hvor der var noget større belegg. Det viser sig mer og mer for hvert år at dette er absolutt påkrevet."*[11] (ANF, 1936, p.8)

The second reason is due to the size of fines. The number of violations would typically decline as the fines increase. If the fines were set high enough, the cost of "cheating" by violating the rules would not be worth it. The report from 1882 mentions changes in the fines, as a response to the problem. Though this point certainly is important, consistent time-series of data is lacking. No consistent series reports the fines, it is only mentioned in some of the reports. However, total revenues from all penalties are described in the reports. But this is not within the scope of this thesis, due to time constraints.

These two reasons can be illustrated by adapting to the framework of Copeland and Taylor (2009). The overseer's problem would then be as follows:[12] Let $\psi^c$ denote the benefits that a fisherman cheating on the rules would get, $\psi$ the benefits gained when following the rules, $\rho$ the probability of being caught and $F$ the fine from violating the regulations. Then,

$$\rho F \geq [\psi^c - \psi] \tag{1}$$

would illustrate the management problem, as the overseer would have to keep fines and enforcement stronger than the expected return from a fisherman "cheating." The overseer introducing a new vessel in 1931 would represent an increase in $\rho$, as this type of monitoring would increase the chances of being detected. And $F$ would represent the fines the overseer were setting, as they for instance discussed the levels of this. Notice that the overseer also need to incorporate a type of limited liability in the problem. Setting

[10] "As noted in last year's report, 3 vessels are too few ... In the upcoming winter, 4 vessels will be inducted by the authorities during the busiest time of the season." (Author's translation)

[11] "Supervision and monitoring was further reinforced with one vessel, and this should be considered for all the districts with higher participation. The recent years have shown that this is absolutely required." (Author's translation)

[12] Note that this serves as an illustration for the fines and enforcement discussion. I assume that the overseer do not explicitly take into account the stock dynamics. And benefits are more loosely defined as "benefits compared to the other fishermen participating."

a too high fine, and the fishermen would just not care any longer. It they where in dire straits and the fines where too high anyway, they might not care for it. Illustration could be the year of 1931, as the fines here could not be too high.

Suppose the reason for the decline was only due to the stronger enforcement, then either i) there were only weak social norms there in the first place, or ii) the social norms eroded as more and more fishermen valued the gains from violating greater than the social sanctions and fines. An argument for i) can be made that the events surrounding the fishery in the years 1900–1940 suggests evidence for weak social norms present altogether. It could be that the fishermen were *only* weighting the gains versus the costs of the fines. Still, one should also bear in mind that the fishery of Lofoten has been a yearly event for several hundred years, and it is therefore likely that there has been some social norms present in the first place. In regards to ii) and given that the social norms were a contagious process present, then perhaps it is more likely just eroding as an increasing number of fishermen where violating the rules and regulations of the co-management.

The third reason is due to exogenous variations. There is a fundamental difference in the fishing grounds of the eastern and the western part of Lofoten. Fishing grounds in the east are more shallow and sheltered, compared to the west of Lofoten with strong currents and typically rough weather (Solhaug, 1983, p.162). Therefore, the variation in participation in these areas is both due to the abundance on the fishing grounds and to changes in the weather. During the years 1905–1920, around 60–70 per cent of the fishermen were participating in the West, and after the year 1920, 20–30 per cent of the fishermen participated in the West (Vea, 2004, p.98). This could to some extent be a part of the reason why the violations increased during 1900–1940. From the year 1936, the weather conditions improved, leading to higher participation in areas such as in the district of Henningsvær and Sørvågen. Here the conditions are better than some of the other areas in eastern of Lofoten that most of the fishing has been in the recent years (ANF, 1936, p.8). This is to some extent a possible reason for the decline in the violations around that time.

### 2.3.5 Motorization

Motorization of the fishing fleet in Lofoten occurred during 1905–1920, in a period that saw a rapid increase in the number of combustion engines installed (see figure 2.5). Compared to other fisheries in Norway, the motorization started relatively late in Lofoten, although once the developments commenced the level of motorization of fishing boats increased faster that any other place in the country. And the novelty of the technological developments in Norway was that the motorization integrated with the old fisherman structure, in contrast to for instance the United Kingdom where the capital intensive steamships altered this structure (Vea, 2004, p.237). It was probably difficult to make any profits from steamboats in Norway the late 1880s (Welle-Strand, 1942, p.15). The reason could be high costs of acquiring and operating such a vessel, the ban of seine and trawls and the shallow and narrow fishing grounds in Lofoten. But even though it may not have altered the structure, it may well have had an impact among the fishermen. Technological change could have influenced the cooperation between them.

The series in figure 2.5 are based on 1905–1988 data from the reports. Motorized boats before this period is negligible, since the first experimentation with combustion engines in Lofoten took place in 1900 (Welle-Strand, 1942, p.22). Following this, in the estimation it will be assumed that there where none motorized boats in the years 1864–1904. The data for 1905 is proxied by observations in the district of Reine, the only district reporting on motorization that year. This is a reasonable approximation, since the report claims that most of the motorized boats and ships were gathered there on the 16th of March (ANF 1905, p.277). From 1906, all the districts reported regularly of motorized boats. And as of 1907, the reports included tables with details on technological aspects. These categories were motorized boats, steamships, boats with shelter and sailboats. These categories change during the period of 1905–1988, but identifying a consistent series motorization has been possible. This was done by adding categories that contained motorization for each year into a series with motorization data.

Five periods can be identified, which is emphasized by four vertical lines in the graph. They indicate the year 1920, 1930, 1940 and 1945. First, the period 1905–1920 where motorization increased from zero to 40 per cent. Secondly, the period 1921–1929 in which

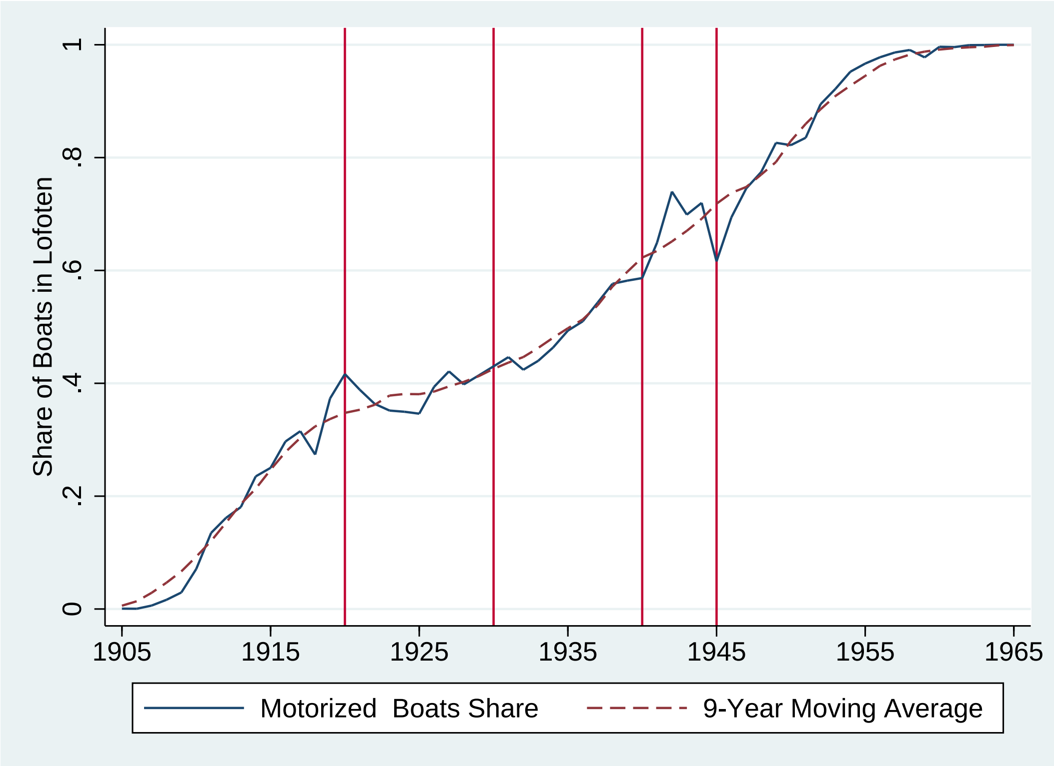


Figure 2.5: Motorized Boats Share in Lofoten (1905–1988)

the overall effect is a halt in motorization. Thirdly, a period 1930–1939 where motorization gains momentum again. Then, a period 1940–1945 which starts and ends at almost the same value. Those years need to be seen in light of the war. Lastly 1946–1963, the last period before all the boats became motorized. The number of participating motorized boats in 1920–1925 were about 2000, and then in 1960–1988 again below 2000.

## 2.4 Estimation

Does technological change erode cooperation in a common pool resource? And more specifically, did the motorization of the fishing fleet increase the violations of the co-management regulations? While the thesis has been descriptive up to this point, a possible relationship between the motorization and violations of §16 is now to be estimated. A method to do this will be presented and explained in the following section and subsections.

While cooperation critically depends on the share of defection in the population, they are unobserved variables. But a measure for defection can arguably be proxied by the violations of the rules and regulations of Lofoten. Based on the explanations of §16, this can be argued to capture the importance of rules and regulations in this regard. However, one should care to take note that this is not a measure of defectors, as in the actual number of users defecting. It is only a proxy for a value of defection. This cannot be anything more, since the data are not from a panel which would follow each and every boat from year to year. Or a panel that perhaps even registered the penalties for each and every fisher together with the boats. Or recognize which boats installed engines when, and so forth. There are limits to these data, and for sure such a data set would have been a considerable advantage.

The defection of cooperation is an unobserved variable. Although unknown, it can arguably be approximated by violations of §16. Cooperation could depend on fishermen following the rules and regulations, typically conflicts over gear and fishing grounds. This is what the violation of §16 index captures. Violations then would be expected to increase in factors that puts a strain on the cooperation. There are three reasons for this which will be commented on. First, as technology changes, it becomes easier to harvest more, and this too puts pressure on the situation. Second, it would depend on the number of participation fishermen. As the users increase, cooperation gets harder to sustain. Lastly, it could be because the prices of the cod increased, which made it tempting to deviate from cooperation. And the enforcers would have to pay a higher price as well in lost opportunity.

The series on motorized boats are a proxy for the technological progress. The motorized boats are assumed to be negligible in the years 1864–1904, for the reasons stated in the previous subsection. This variable is included in the regression to see whether motorization has had an effect on defection in Lofoten. While this measure has its limits, as other technological development also occured, it may not be a reliable measure for the whole period, as of the 1930s with trawl and 1950s with echo sounder, and 1950 with seines. But it probably is a good indicator for technological progress during 1905–1950. Prior to the developments of 1905, there were some notable technological changes such as gill nets and long lines in the beginning of 1800, and later glass floats to the gill nets. However, these improvements is likely to never have materialized into higher productivity during 1815–1880 (Solhaug, 1983, p.584).

### 2.4.1 The Regression Model

Using a semi-logarithmic trend break model,

$$\begin{aligned}\ln P_t = \alpha + \delta_1 \ln S_t + \delta_2 \ln F_t + \delta_3 M_t + \gamma_1(M_t \times s_1[1905-1920])+ \\ \gamma_2(M_t \times s_2[1921-1929])+ \\ \gamma_3(M_t \times s_3[1930-1939])+ \\ \gamma_4(M_t \times s_4[1940-1945])+ \\ \gamma_5(M_t \times s_5[1946-1963])+ \\ \xi_t,\end{aligned} \tag{2}$$

where $t$ denote the year index, $P_t$ the violations of §16, $S_t$ the proxy for fish stock, $F_t$ the fishermen, $M_t$ the share of motorizedboats, $s_1[1905-1920], \ldots, s_5[1946-1963]$ the time break dummies and $\xi_t$ the disturbance. The dummies ends in 1963, as 1964 is the first year of 100 per cent motorized boats. The dummy for period $s_0[1864-1904]$ is omitted due to perfect multicollinearity. The dummies are equal to one for the respective years, zero otherwise. The time length of the dummies corresponds to those in figure 2.5.

Fish stock will be approximated by catch-to-effort ratio. No direct measure on effort of harvesting exist. Therefore, boats participating will be a proxy for effort. This is far from perfect, since intensity of the fishing effort is not fully reflected in this measure (Hannesson et al., 2010). For instance, a direct measure of hours spent on harvesting would have been an advantage. However, this is the data available in the reports and will be utilized in estimation. Motorized boats is a share, that takes values between 0–1, and since the whole period 1864–1988 is estimated the logarithm is not appropriate here.

There is reason to suspect that the disturbance term $\xi_t$ is not independently and identically distributed (iid) over time. That is, it may depend on its past, present and future values. In this estimation, strictly exogenous regressors and error term following up to a first-order auto-correlation (AR(1)) will be assumed. In the presence of auto-correlation, the ordinary least squares (OLS) estimator will produce consistent and unbiased estimates. However, the variance of the coefficients will be incorrect, therefore they cannot be used for inference. In this case, OLS will not be the best linear unbiased estimator (BLUE) as other more efficient estimators exists.

### 2.4.2 Feasible Generalized Least Squares

Estimating (2), a feasible generalized least squares (FGLS) approach will be used, namely the Prais-Winsten (PW) estimation developed as an improvement of the Cochrane-Orcutt method by Prais and Winsten (1954). This procedure relies on two critical assumptions; disturbance following a first-order autoregressive (AR(1)) process, and strict exogeneity of regressors. Strict exogeneity means that all the regressors must be uncorrelated with the error term in all periods; past, present and future.

Omitting the dummies for ease of exposition, the regression model can be written more generally as[13]

$$y_t = \boldsymbol{X}_t\boldsymbol{\beta} + e_t, \tag{3}$$

where $y_t$ is the regressand, $\boldsymbol{X}_t = (1, x_{1t}, \ldots, x_{nt})$ is a $1 \times n$ row vector of the regressors, $\boldsymbol{\beta} = (\beta_0, \beta_1, \ldots, \beta_n)^\top$ is a $n \times 1$ column vector of coefficients and $e_t$ the disturbance is assumed to follow stationary AR(1) process

$$e_t = \rho e_{t-1} + \eta_t, \qquad \eta_t \overset{iid}{\sim} (0, \sigma_\eta^2), \qquad |\rho| < 1. \tag{4}$$

The auto-covariance of (3) can be written as

$$\boldsymbol{\Omega} = \frac{\sigma_e^2}{1-\rho^2}\begin{bmatrix} 1 & \rho & \rho^2 & \cdots & \rho^{T-1} \\ \rho & 1 & \rho & \cdots & \rho^{T-2} \\ \rho^2 & \rho & 1 & \cdots & \rho^{T-3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \rho^{T-1} & \rho^{T-2} & \rho^{T-3} & \cdots & 1 \end{bmatrix} \tag{5}$$

The GLS estimator is $\widehat{\boldsymbol{\beta}}_{GLS} = (\boldsymbol{X}^\top\boldsymbol{\Omega}^{-1}\boldsymbol{X})^{-1}\boldsymbol{X}^\top\boldsymbol{\Omega}^{-1}\boldsymbol{y}$, and the variance $\mathrm{Var}\,(\widehat{\boldsymbol{\beta}}_{GLS}) = (\boldsymbol{X}^\top\boldsymbol{P}\boldsymbol{P}^\top\boldsymbol{X})^{-1} = (\boldsymbol{X}^\top\boldsymbol{\Omega}^{-1}\boldsymbol{X})^{-1}$. Let $\boldsymbol{P}$ be a matrix with the property that $\boldsymbol{P}\boldsymbol{P}^\top = \boldsymbol{\Omega}^{-1}$

[13] This subsection on FGLS follows the treatment in Davidson and Mackinnon (2009, chap. 7).

and $\boldsymbol{\Omega}$ be an invertible matrix.[14] The matrix $\boldsymbol{P}$ depend only on the parameter $\rho$:

$$\boldsymbol{P}(\rho) = \begin{bmatrix} \sqrt{1-\rho^2} & -\rho & 0 & \cdots & 0 \\ 0 & 1 & -\rho & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{bmatrix} \tag{6}$$

Multiplying (3) with $\boldsymbol{P}^\top$ gives

$$\boldsymbol{P}^\top y_t = \boldsymbol{P}^\top \boldsymbol{X}_t \boldsymbol{\beta} + \boldsymbol{P}^\top e_t, \tag{7}$$

thus the covariance of the transformed disturbance $\boldsymbol{P}^\top e_t$ becomes

$$\mathrm{E}\,(\boldsymbol{P}^\top e_t e_t^\top \boldsymbol{P}) = \boldsymbol{P}^\top \mathrm{E}\,(e_t e_t^\top) \boldsymbol{P} = \boldsymbol{P}^\top \boldsymbol{\Omega} \boldsymbol{P} = \boldsymbol{P}^\top (\boldsymbol{P}^\top \boldsymbol{P})^{-1} \boldsymbol{P} = \mathbf{I}\,, \tag{8}$$

showing that the transformed covariance is the identity matrix $\mathbf{I}$. The matrix $\boldsymbol{P}$ only depends on the parameter $\rho$, and by regressing with the PW command in Stata, the program finds an estimate of this parameter which minimizes the sum of squares (Becketti, 2013, p.187).

[14]That is, $\boldsymbol{\Omega}\boldsymbol{\Omega}^{-1} = \boldsymbol{\Omega}^{-1}\boldsymbol{\Omega} = \mathbf{I}$

# 3 | Results

The regressions are done by successively adding the regressors, each regression carried out by estimating with the following variable. All the estimations have been carried out in Stata. First estimation starts with violations of §16 on catches per boats. In the second estimation fishermen are added. Third estimation includes the share of motorized boats. Lastly, the fourth estimation with time-break dummies are included. All estimations are done with the Prais-Winsten method, under the assumption of strictly exogenous regressors and disturbance following an AR(1) process. The result of estimations are shown in table 3.1. The table reports of estimation from the second column towards right, as the regressors are added. At the bottom of table are the reports of sample size $N$ (years), the $F$-value, the estimation of $\rho$, Durbin-Watson (DW) statistic; original and transformed, the value of "goodness of fit" $R^2$ and adjusted $R_a^2$.

Sample size $N$ (years) in all regressions are equal to 125. It is assumed that there where none motorized boats before 1905, for reasons stated in subsection 2.3.5. Goodness of fit $R^2$ takes value between 0–1, indicating how good the regression model suits the data. Values close to 0 indicate low explanatory power. Typically, $R$ is increasing in variables, as more variables are added gives a better fit. Therefore the adjusted goodness of fit $R^2$ is reported, giving a "penalty" for adding irrelevant variables. Note that $R^2$ and $R_a^2$ are not test statistics. The parameter $\rho$ reports the iterated value from the PW estimation, which must take a value less than the absolute value of 1 for stationarity (see subsection 2.4.2). Original Durbin-Watson reports the statistic before the transformation has taken place, and the Durbin-Watson transformed statistic is after the FGLS estimation. Durbin-Watson statistic takes a value in the 0-4 range. Range 0–1 means strong indication of positive autocorrelation. Lower scale of 1–2 give reason to be suspicious. Upper range of 1–2 is perfectly fine. Value of 2 is a sign of no auto-correlation. And then 2–3 gives reason to be suspicious, and value 3–4 indicates a strong negative autocorrelation. DW $\approx 2$ is a good rule of thumb, but when more uncertain values appear, one can check the critical upper and lower DW-values in a table.

Four estimations are to be commented on. First result is estimation of violations of §16 on catches to boats, the proxy for stock. Coefficient is 0.552 with t-value of 2.41, which is significant at a 5 per cent level of significance. It means that a one unit increase in catch to boats leads to a 0.552 unit increase in violations. The constant is 3.568 with t-value 6.00. This is significant at a 1 per cent level of significance.The F-value of first regression is 8.62. Durbin-Watson statistic original is 0.648 and transformed Durbin-Watson is 2.382. The original Durbin-Watson show that OLS estimation is problematic. But the transformed Durbin-Watson suggest that feasible generalized least squares handles the autocorrelation sufficiently. The parameter $\rho$ is 0.862. Recall that this had to be less than 1 in order to have stationarity. The goodness-of-fit measure $R^2$ is 0.066, so this model does not have much explanatory power.

Second estimation includes the fishermen. Stock proxy turns out to be stronger compared to the first regression. The coefficient is 0.697 with t-value of 3.43. It is significant at a 0.1 per cent level of significance. The coefficient for fishermen is 1.904 with a t-value of 6.66. It is significant at a 0.1 per cent level of significance. The effect of fishermen on violations is as expected: More participation associated with higher violations, which is a crowding externality. The constant term change sign and increase compared to first regression, -14.80 and t-value of -5.20. It is significant at a 0.1 per cent level of significance. The reason must be due to added fishermen variable: Intercept has to change for the model to fit. Goodness of fit $R^2$ is 0.297. This is an improvement compared to last regression. Adjusted goodness of fit measure $R_a^2$ is 0.285. DW statistic original 0.586 and transformed 2.256. The F-value is 25.72.

Third regression includes the share of motorized boats. The coefficient effort to boats is 0.578 with a t-value of 2.73. It is significant at a 0.01 level of significance. The coefficient for fishermen is 2.237 with a t-value of 6.54. It is significant at a 0.001 level of significance. The effect of fishermen turns out to be more important as the motorized boats are added to the series. The motorized boats coefficient is 1.29 with a t-value of 1.79. The coefficient insignificant at 5 per cent level of significance. It is an expected result, as motorization is interesting only during the years 1905–1970. The constant is still negative; -18.40 and a t-value of -5.25. It is significant at a 0.1 per cent level of significance. The F-value decrease to 18.67. The parameter $\rho$ is 0.744. It is clearly less than one in absolute value, and close to that of the second regression. The Durbin-Watson original statisitic 0.715, transformed the transformed Durbin-Watson is 2.228. $R^2$ improves as the value is higher than last regression. Reported value of $R^2$ is 0.316. This is expected as a a new variable is added. The adjusted goodness of fit $R_a^2$ is 0.299.

Fourth regression includes the trend break dummies. The catch-to-effort coefficient is almost identical to the previous regression. The coefficient is 0.556 with a t-value of 2.58. It is significant at a 5 per cent level of significance. The coefficient of fishermen is still close to the previous one, it is 2.131 with a t-value of 6.11. It is significant at a 0.1 per cent level of significance. The coefficient of motorized boats is 1.587 with a t-value of 2.28. It is significant at a 5 per cent level of significance.

The first coefficient for interaction dummy years 1905–1920 is 5.018 with a t-value of 3.70. It is significant at a 0.1 per cent level of significance. The effect is strong, and as expected because the previous graphs has suggested a close relationship. The second interaction coefficient is for the years 1921–1929. It is 3.251 with a t-value 2.91, and is significant at a 1 per cent level of significance. The third interaction term is for the years 1930–1939. The coefficient is 1.248 with a t-value of 1.27. It is insignificant at a 5 per cent level of significance. The fourth interaction dummy is for the years 1940–1945. The coefficient is 0.150 with a t-value of 0.19. It is insignificant at a 5 per cent level of significance. The sixth interaction dummy is for the years 1946–1963. The coefficient is -0.922 with a t-value of -1.77, and is insignificant at a 5 per cent level of significance.

The F-value drops a little compared to the third regression. The F-value is 13.85 compared to 18.67 from third regression. The Feasible generalized least squares parameter $\rho$ is 0.493. It is lower compared to all the previous estimations. The Original Durbin-Watson was 1.119, suggesting auto-correlation. The transformed Durbin-Watson turns out to be successful with a statistic of 1.992. Goodness of fit increases to 0.488 from previous regression, thus the regression model explain almost 50 per cent of the violations of §16. Adjusted $R^2$ gives a small penalty as the value is 0.453.

The insight from table 3.1 is that fishermen and catches to boats are significant variables when it comes to explain violations. And the effect of motorized share of boats is strong for the years 1905–1929, as the interaction dummies highlights the explanatory power of this variable during these years. It means that motorization explains most of the violations during those years, but is of less importance for the other periods. This result does not necessarily imply that there is causality. In this case, a solution is discussing pro and contra which is then a foundation to base a conclusion upon. For this reason, the next chapter will have a discussion on the possible mechanisms in which violations can have been affected by fishermen, catches to boats and motorized boats share.

Table 3.1: Estimation of Violations of §16

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | lnP | lnP | lnP | lnP |
| lncatchesprboats | 0.552* | 0.697*** | 0.578** | 0.556* |
| | (2.41) | (3.43) | (2.73) | (2.58) |
| lnfishermen | | 1.904*** | 2.237*** | 2.131*** |
| | | (6.66) | (6.54) | (6.11) |
| motorshare | | | 1.294 | 1.587* |
| | | | (1.79) | (2.28) |
| c.motorshare#c.s1 | | | | 5.018*** |
| | | | | (3.70) |
| c.motorshare#c.s2 | | | | 3.251** |
| | | | | (2.91) |
| c.motorshare#c.s3 | | | | 1.248 |
| | | | | (1.27) |
| c.motorshare#c.s4 | | | | 0.150 |
| | | | | (0.19) |
| c.motorshare#c.s5 | | | | -0.922 |
| | | | | (-1.77) |
| _cons | 3.568*** | -14.80*** | -18.40*** | -17.60*** |
| | (6.00) | (-5.20) | (-5.25) | (-4.99) |
| $N$ | 125 | 125 | 125 | 125 |
| F | 8.616 | 25.72 | 18.67 | 13.85 |
| rho | 0.862 | 0.758 | 0.744 | 0.493 |
| dw_0 | 0.648 | 0.586 | 0.715 | 1.119 |
| dw | 2.382 | 2.256 | 2.228 | 1.992 |
| $R^2$ | 0.0655 | 0.297 | 0.316 | 0.488 |
| $R^2_a$ | 0.0579 | 0.285 | 0.299 | 0.453 |

$t$ statistics in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

# 4 | Discussion

This chapter is organized as follows. Section 4.1 discuss the main findings of the regressions; emphasis is given on possible mechanisms in which motorization could lead to increasing violations. Section 4.2 discuss reliability of the estimation and other econometric issues of internal validity; focusing on omitted variable bias, simultaneity bias, measurement errors and misspecification of the functional form. Section 4.3 discuss the implication of policy on results; as in external validity of the results and generalizability. Lastly, section 4.4 comment on three ideas which could be elaborated in further studies.

## 4.1 Main Findings

Does technological progress erode cooperation in a common-pool resource? And did the motorization in Lofoten lead to more violations in the co-managed resource? The regression results show that motorization during 1905–1929 was associated with increasing violations of the rules and regulations set by the local committees. The effect of motorization on violations is strong, and in line with theory. Technological change was predicted to put a strain on cooperation. In this case, approximated by violation of the time-allowance and fishing grounds regulations. The effect of fishermen is significant during the whole period considered. This represents the crowding externality. In this interpretation, increasing number of users would put a higher strain on cooperation. Lastly, the stock variable approximated by the catch-to-effort ratio is significant during the whole period. In the following, the possible explanations of why violations may have been affected by these variables will be discussed. First how the mechanism in which fishermen and catch-to-effort possibly led to higher violations, and then how would motorization led to violations.

The effect of fishermen on violations is intuitive. It is due to the crowding externality. Clearly, increasing participation of fishermen on the fishing ground would, *ceteris paribus*, lead to higher chances of conflicts over gear and boats. Few of these problems would have been present with low participation. The effect of this is as expected, with a positive relationship for the whole estimation period. A result that is in line both with the history of conflicts and events as typical stories of conflicts over gear types and space echoes through the history of Lofoten, and with economic resource theory.

The second effect is from the stock proxy, the catch-to-effort variable. The sign is positive, which indicate that violations are increasing the in the catches-to-effort ratio. This effect is could be due to to weighing the expectations of upside-vs downside with a high abundance. It means that a bigger stock will make the gains from "cheating" on the co-management larger. And following this logic, the pressure on sustaining the co-management will thus increase.

There are three mechanisms to comment upon, in which motorization could have influenced violations. The first mechanism is due to an increasing upside of harvesting. The second mechanism is because of higher mobility of the fleet. And the third mechanism is caused by other technology working together with motorization.

First of all, motorized boats would have a superiority in speed. With higher speed, they would arrive earlier on the fishing grounds. The vessels with installed engines would have a significant advantage over the others. They would get faster to the fishing grounds, putting out nets faster or getting larger catches etcetera. That means superiority of new versus old technology. As upside from violation would be higher expected catches, because motorboats could possibly gain more from "cheating" on the cooperation. However, this mechanism could work the other way around as well. If motorboats had the advantage of their mobility, then one could argue that the should be no reason to leave harbor before the others. Because of the speed, they would still get to the fishing grounds first. Moreover, it could be the fishermen *without* motorized boats that started violation in order to gain access to the grounds earlier that the others.

Secondly, violations could increase due to higher mobility of the fleet, that is a mobi-

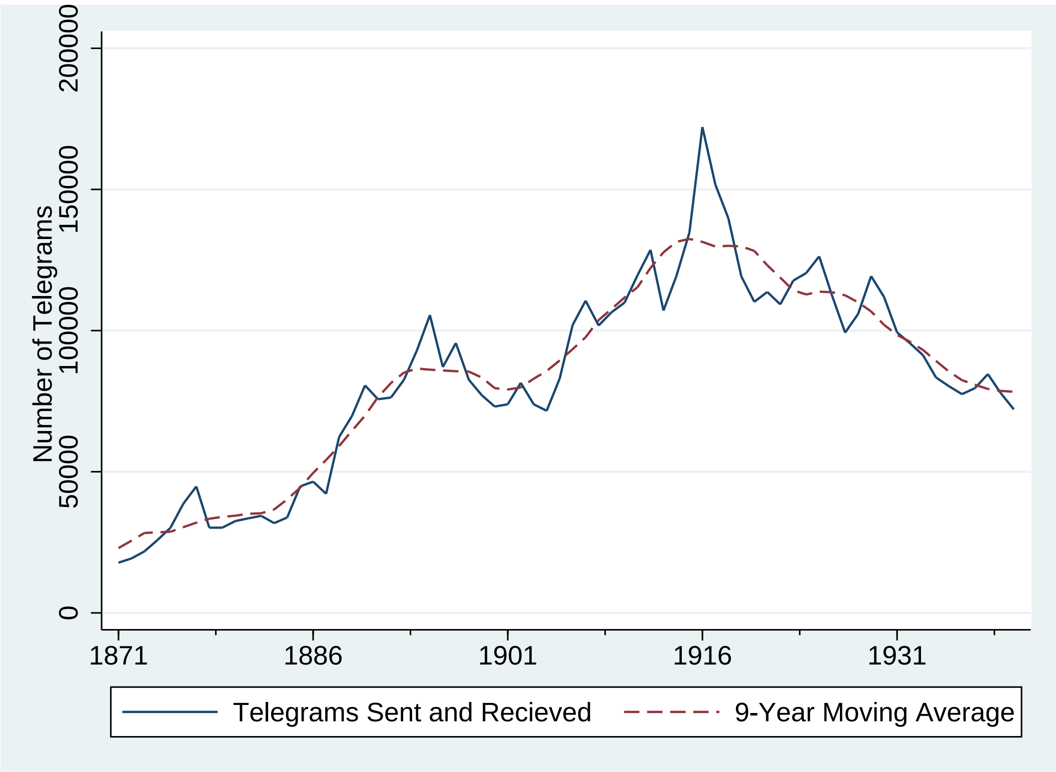


Figure 4.1: Telegrams Sent and Received (1871–1940)

lization mechanism. Chances of crowding would be more likely, as more boats would gather on the abundant fishing grounds compared to previous years. High abundance in particular areas would tend to gather the fishermen there instead. News of this year's "good" locations could be spread by "word of mouth" or by telegraphs. Indeed, a series shown in figure 4.1 from the reports on telegrams sent and received during 1871–1940 shows increased activity up to 1916, but then a decline compared to the "pre-motorization" years. The telegraph starts to matter around from the 1880s, but the the effect is more important during the motorization years (Welle-Strand, 1942, p.38). An example of – seemingly insignificant – one technology gaining importance in tandem with another. It might be a strong statement, but at least telegrams sent and received were of *relatively* little importance before motorization. Due to the faster mobilization, crowding would probably occur more frequently.

Thirdly, motorization must be seen in the light of new vs old technology. Some of the new vessels were equipped with dories. That is, larger "factory-type" of vessels that were carrying smaller boats – dories – which were deployed once the vessels had arrived on the fishing grounds. Especially the years 1905–1920 could be seen in relation to this. Fishing was done in a more "American fashion." This typically led to some conflicts, since the dories were not particularly seaworthy. Conflicts arose as the boats and gear were crossing on the fishing grounds. This was especially accentuated in bad weather, with wind and waves on shallow fishing grounds (Welle-Strand, 1942, pp.102–105).

## 4.2 Internal Validity

In regard to the internal validity of these results, there are four econometric issues that will be discussed. First, a discussion of omitted variable bias. Second, a discussion on simultaneity bias. Third, a discussion on measurement error. Fourth, a discussion on misspecification of the functional form.

Firstly, the model estimated could suffer from an omitted variable bias. It means that an important variable that explains the variation in violations has not been included in the regression. For instance, violations may just have increased in the motorization years due to more reporting. A stronger force of monitoring vessels would just discover that violations where taking place. Or it could be due to the price of the resource, which could have consequences for the overall conclusion of the estimation results. Indeed, figure 4.2 suggests that price may have a say in the matter. The data are from the report of 1928 (ANF, p.45). This series show the value of one gutted cod in *"øre."*[1] Incorporating such a series in the estimation has posed a large problem due to inconsistency of the reporting. First of all, the series goes only back to 1889. Secondly, and more importantly, the reporting change. The price of one gutted cod change to price of gutted cod per kilo from 1929. This pose a problem in transformation which needs to be dealt with. And lastly, as of 1940, the reporting changes altogether. The reports of prices are more detailed, with several series on prices. However, gutted cod is as far as one can see not included. This problem could perhaps have been solved by composing an index of the other data. For instance an index which could to some extent fit with series from 1889–1929. Or one could perhaps find other sources of the price of cod in Lofoten, perhaps dried fish, etcetera. The focus of this thesis has been on technological changes, and not the impact

[1] Which is (1/100) NOK.

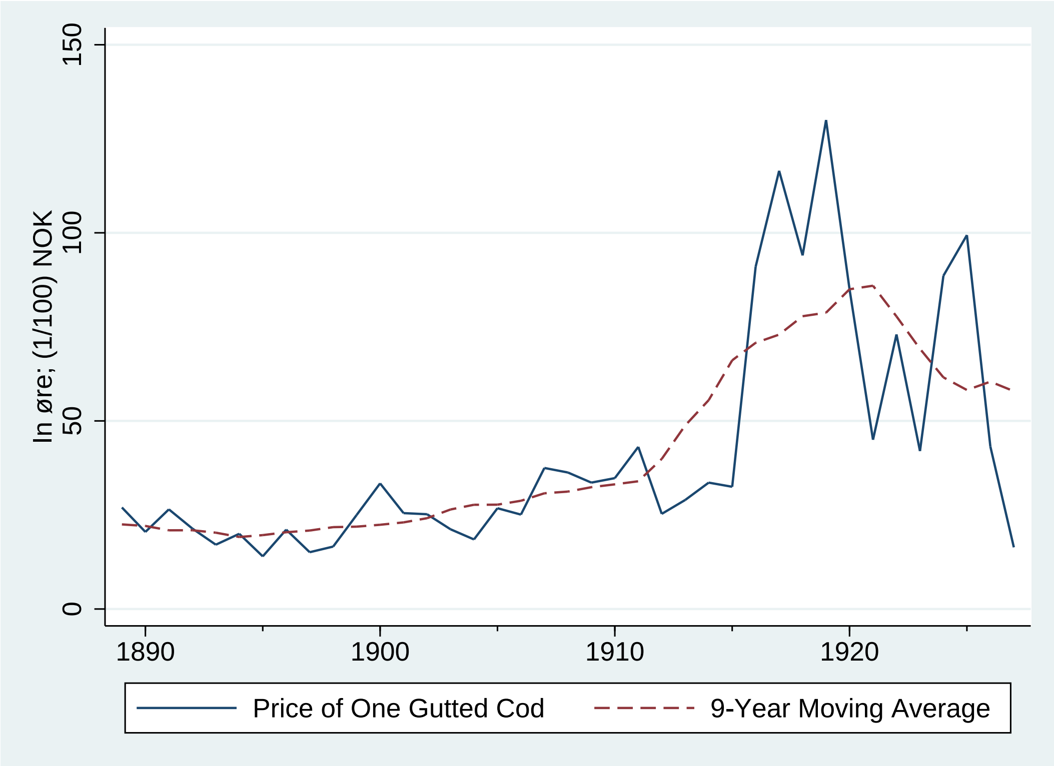


Figure 4.2: Price of One Gutted Cod (1889–1927)

of prices on cooperation. However, one should note that prices could have an impact on the overall results of the estimation.

In the case of an omitted variable bias, such as the price of cod, the coefficient for motorization will either underestimate or overestimate the effect. If the correlation between the price and violations is positive, as well as the correlation between price and motorization, it would lead to a overestimated motorization coefficient. Calculations of the correlations has been carried out, which were based on the data from the short series of the years 1871–1927. This could give information on the direction of the bias, and to some extent the magnitude. The correlation between the motorized boats share and the logarithm of the price of gutted cod is 0.717. Clearly, this is positive and highly correlated. The correlation between the logarithm of §16 and the logarithm of the price is 0.567. Therefore, there is reason to believe that the results from the regression overestimate the effect of motorized boats based on this indication from the sample 1871–1927.

Secondly, there could be problems due to simultaneity bias. The assumption made was that the regressors were strictly exogenous. This means that there for instance should be zero contribution from violation to motorization. In other words, that violations of §16 are exogenous with respect to motorization. Or in the widest interpretation of the result, it would mean that defection would not affect the technology, both the initial conditions and later the rate of changes. However, if a co-managed system to some extent were based on social norms, then behavior could affect the norms. But norms may also affect the behavior. For instance, once the process of motorization had commenced, it could gain extra momentum as other fishermen observed the high profits from the cheating motorized boats, and for this reason only install an engine the following year. Following this logic, a system modeling would be important, as violations then would be part of a larger system which has not been taken into account.

Thirdly, the model could suffer from a misspecification of the functional form. It was assumed up to first-order auto-correlation. But the disturbances could be of a higher order. This could possibly be corrected for, but could perhaps more likely be a reflection of a general misspecification of the model. Or the model could for instance suffer from other misspecification, such as a variable not squared.

Lastly, there may have been measurement issues. This means that a variable do not reflect the true value. At this point, one can only refer to the discussions in section 2.3 for each of the variables. Although this might be an issue, it has been dealt with utmost care at every stage. However, it cannot be ruled out completely that some of the variables are suffering from this. But this is the limit of the historical data of a time-span of 125 years.

## 4.3 External Validity

Given the estimation method, and assuming internal validity for the sake of discussion; the results show that technological changes need to be taken into consideration in co-management systems. And the discussion on violations revealed the importance of monitoring and fines. Here it was pointed out that care must be taken as fines cannot be too high due to issues of limited liability. That is, once a critical threshold is reached it does not matter to the users any longer, as they cannot pay the fine anyway. It is an argument for the "resolution" of the fines, as they need to be "fine-tuned" due to limited liability-type of issues discussed in the violations subsection 2.3.4.

The discussion here has been limited. It has been relatively silent on cooperation and long-run impact of technology. The thesis do not elaborate further on the efficiency of cooperation when it comes to managing the resource stock. This is an interesting point, but out of the scope for this thesis. One can only point out that in the late 1980s the fishery of Lofoten was in need of regulations of a quota system, ending the Lofoten years of open-access as complete regulations with quotas being incorporated. See Holm et al. (2000) for an interesting discussion of co-management in Lofoten as in managing fishing grounds or the stock.

Although the results show that technological changes are important when it comes to cooperation, the result from the Lofoten fishery may not be completely generalizable. For instance, two arguments on the contrary could be raised: Firstly, it may be a special case due to the uniqueness of shallow fishing grounds and weather conditions in Lofoten. Such situations may not be the case with open-access fisheries elsewhere. Secondly, it may be a special case given the time-period this event occurred. Clearly, events taking place over a hundred years ago may not be the same as technological changes today. Referring to the third mechanism with conflict over dories and fishing grounds, new technology as of today might have led to different situations than they did at that time.

Although these points have been made; this is not to say that historical events are of less importance. There are lots of lessons to be learned from the history. For sure, understanding the past is vital in order to make predictions into the future.

## 4.4 Further Research

By working with thesis, several ideas has evolved which could be elaborated in further studies. Indeed, the annual Lofoten reports and the sources on history of the fishery contain a large amount of interesting information to be incorporated into further studies. Going further into the sources, adding details to the events related to the motorization years could lead to new and better ideas to be exploited. However, the ideas presented here is limited to three, which will be commented.

First of all, the price of the cod needs to be exploited further and incorporated more into an analysis. How did the price of the resource vary over time in the years 1864–1988? How does the changes in the price around 1920 affect the general results of this analysis? Although the data on price are limited in the first years of the reports, later they are included. One could also compare the prices with other sources in Norway and with other countries. It would be interesting to exploit if there was any significance to the monopoly situation with the Raw Fish Act of 1939. This should definitely be exploited further. One should study the changes in prices and try to get the whole picture on the cooperation.

Secondly, it would be of interest to go further into the history and events around the changes in violations during the years 1905–1940. The idea is to explore if the violations dropped as a response to increasing fines. Even though no consistent time-series exist on the fines in the reports, an index could perhaps be made. This could consist of the income that the authorities had from the violations every year. Furthermore, this together with the penalties given could give an indication of the fines given, shedding light on the changes in the number of violations.

Thirdly, exogenous variation such as the weather conditions could be exploited. Possibly, one could create an index of weather related events such as fishing days in the eastern or western fishing grounds of Lofoten. Or perhaps one could use data on "good days of fishing" in an attempt to proxy for effort. Data on good and bad weather does exist, but not consistently for the 1864–1988 period. It would be tricky, though, as such an index would need to take account of new technology making bad weather less of a problem, at least to some extent. To illustrate the point; compare good fishing weather days in 1864 to 1988. Surely, boats today can handle the bad weather better, and should, *ceteris paribus*, lead to fewer days categorized as "bad fishing days." On the other hand, hard times and little outside opportunities back in 1864 would perhaps give incentives to take extra risks for the fishermen.

# 5 | Conclusion

This thesis has focused on changes in the technological parameter, and more specifically the impact of motorization on the co-management in Lofoten. Does technological progress erode cooperation in a common-pool resource? Would a significant shock in technology have consequences for the co-management, as in increasing violations of the rules and regulations set by the co-management? The hypothesis to be tested was: Violations of the rules and regulations set by the co-management will increase during a rapid technological change.

The main issue of this thesis has been to exploit the insight from theories in resource economics emerging in the recent years. These models were inspired by case studies and lab experiments of people working together, examples of co-management in an open-access resources – in contrast to the "tragedy of commons" metaphor. The models depend critically on three parameters. First, cooperation depended on the technological changes; as technology would increase the contemporaneous externality. That is, crowding would encounter more frequently with higher mobility, and it would increase the intertemporal exteranlity, as new technology increases the pressure on the resource stock. Second, cooperation depended on the population; as more users would render social norms harder to sustain. The social norms sanctions would not impose enough restrictions on the users, as the gains by ignoring the rules and regulations would be higher. The cooperation could then no longer hold back the increasing pressure on the crowding contemporaneous externality. Clearly, the externality of crowding increase in the number of users. Lastly, the cooperation depended on price of the resource; as increasing prices would favor more cheating, and thus increase the incentives to defect.

The thesis exploits the open-access fishery of Lofoten during the years 1864–1988. Lofoten was chosen, because it is commonly regarded as an example of a successful co-managed open-access resource. In chapter 1 it was explained that the co-management in Lofoten corresponded to many of the criteria developed by Ostrom. In Lofoten there were committees which included the fishermen, therefore integrating the fishermen into the governance of the resource. The development in the co-management was elaborated, where the emphasis were on some examples in history that must have shaped the culture of the Lofoten fishery. The data set is based on the historical annual Lofoten reports. Together with the reports and other historical literature, a period of rapid technological change was identified. This occurred during the years 1905-1920 when the motorization increased from 0 to 40 per cent. Motorization was then argued to be a proxy for technological change. Coinciding with these changes, violations of the rules regarding time-allowance and fishing grounds started to increase. Violations of those rules were included in an index of §16 that consisted rules and regulations of the time-allowance and fishing grounds. Because these rules and regulations were set by the committees in the co-managed fishery, it was argued to be a proxy for defection of the cooperation.

A regression model was presented, in which the violations of §16 was estimated as the proxy for defection. The regression included variables: fishermen, catches-to-effort, motorized boats and time-break trend dummies. Due to suspicion of serial-correlation, estimation was carried out by the Prais-Winsten method. The estimation hinged on two assumptions: i) the regressors were assumed to be strictly exogenous and ii) the disturbance assumed to follow up to an first-order autoregressive process. It was argued that the violations could perhaps influence the speed of technological progress. Based on the assumptions mentioned above and internal validity, the conclusion follows: Motorization was associated with a strong and significant effect on violations of the rules and regulations of the co-management. Further, this could be interpreted as a technological change affecting the cooperation of a common pool resource. The strain on this cooperation would then increase, as the chances of crowding and overcommitment in the fishery increased.

Given the estimation method used and the assumptions stated, this result encompass the theory. A significant technological change is associated with eroding cooperation in a common pool resource. And the pressure towards stronger rules and regulations. This type of problem was illustrated with an example from the Lofoten report of 1935, as the overseer was facing difficulties of enforcement of the rules and regualtion. Possible mechanisms where identified. Most likely, the motorization led to higher mobility of the fleet increasing the chances of crowding more frequently. This process was also catalyzed by the telegraph and newer technology such as dories.

The analysis of the historical fishery of Lofoten show the importance of technological changes on cooperation in a common-pool resource. At the same time, the findings suggest that participation and prices also are vital for the total picture. These three parameters were shown to increase to some extent during the year of extensive progress of motorization. The research reveals the importance of enforcement in a co-managed resource, as it is likely that stronger monitoring and increasing fines were part of the reason for the declining violations. One could argue that the technological changes and progress occurred one hundred years ago is different from developments of today. Still, it is about *people* governing a resource, and as such, the technological changes during the motorization is as relevant today as ever.

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